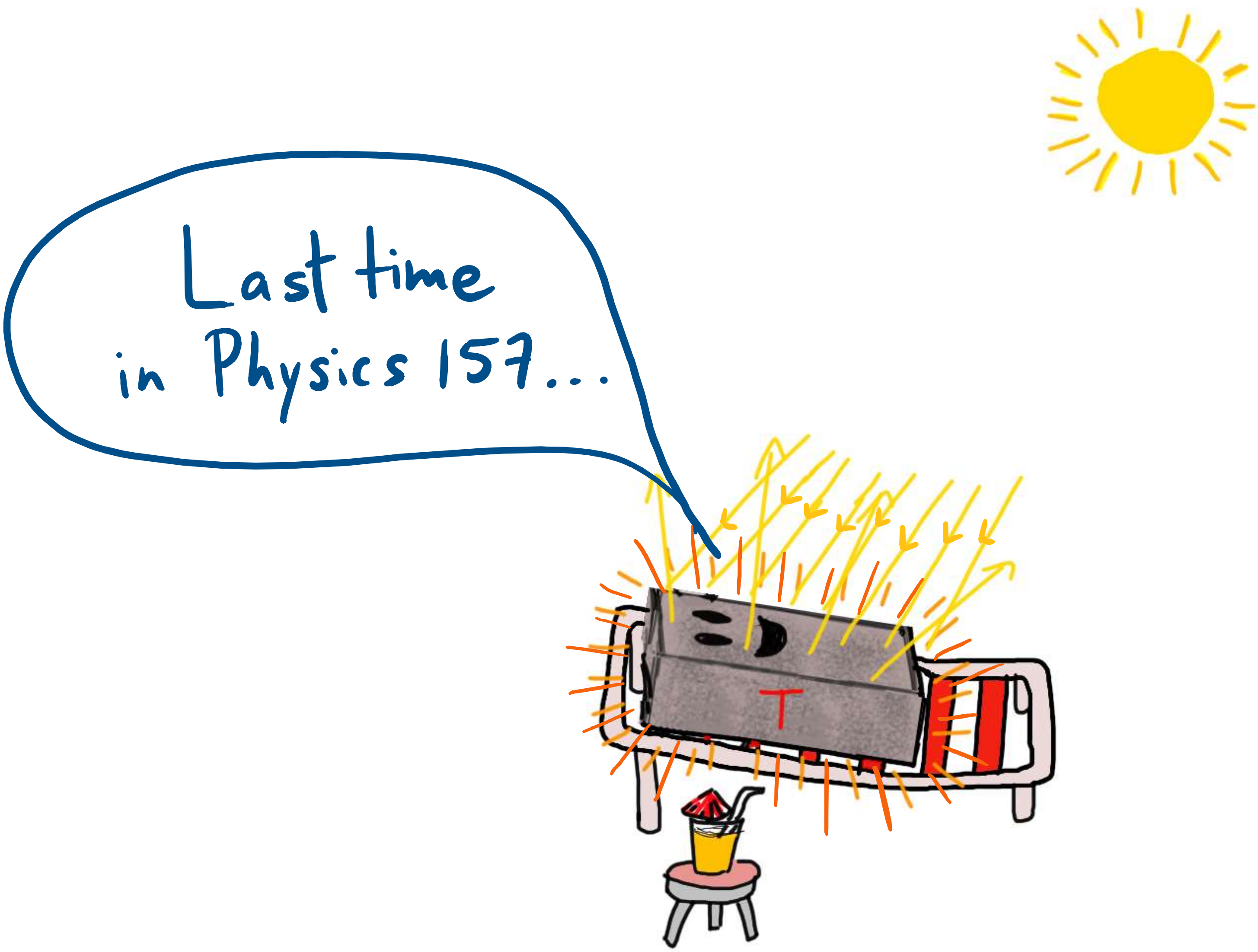

Last time in Physics 157...
T

Heat current from radiation

$$H = A \cdot e \cdot \sigma \cdot T^4$$

- heat current → H
- surface area → A
- emissivity → e
- Stefan-Boltzmann constant → σ: $5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$

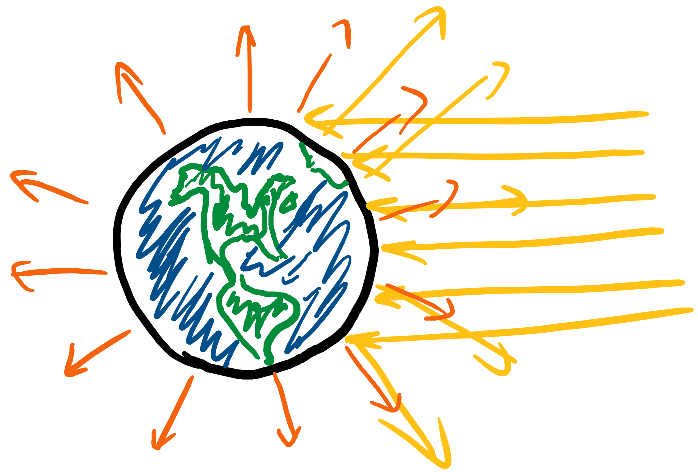
A planet with radius r = 6400km lies at a distance R = 150,000,000km from a yellow star with temperature T = 5700K and radius R_S = 695,000km. **Estimate the surface temperature of the planet.**

The planet has **albedo** (fraction of incident light reflected) A = 0.37 and emissivity *e* close to 1.

Key relation for steady-state heat flow:

$$H_{in} = H_{out}$$

Our problem:

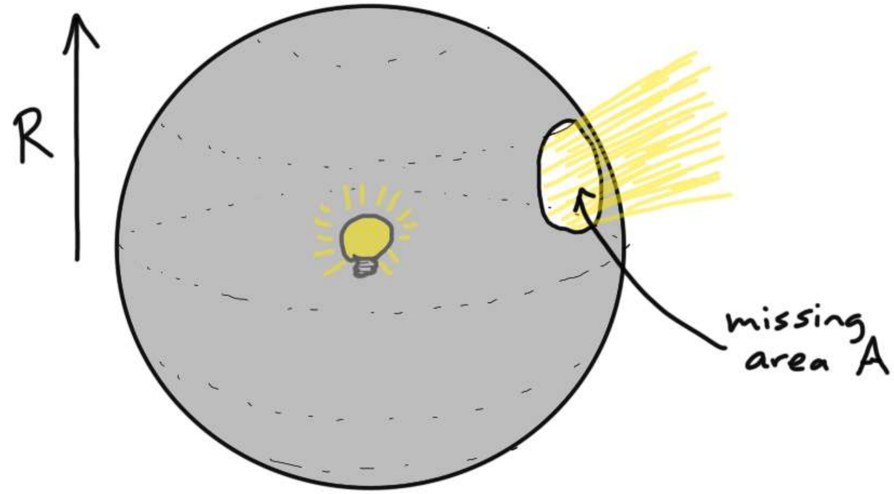


H_{in}: absorbed sunlight

H_{out}: IR radiation $= A e \sigma T^4$

What is H_{in}?

A light bulb producing 100W of radiation is placed at the center of a sphere of perfectly absorbing material, with radius R. A hole is cut into the sphere, removing an area A of material. What is the rate of energy flow through the hole?



A) 100W
B) 100W × A
C) 100W × A/R^2
D) 100W × $A/(\pi R^2)$
E) 100W × $A/(4 \pi R^2)$

Assume the light from the bulb spreads out uniformly in all directions.

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* SPECIAL OFFICE HOURS: today 11-12:30, 3:30-4:30
* MIDTERM Q+A: Tuesday 5-7pm, Life 2201 (this room)
* Midterm Format: Conceptual Multiple Choice + Problems
  review clicker probs!

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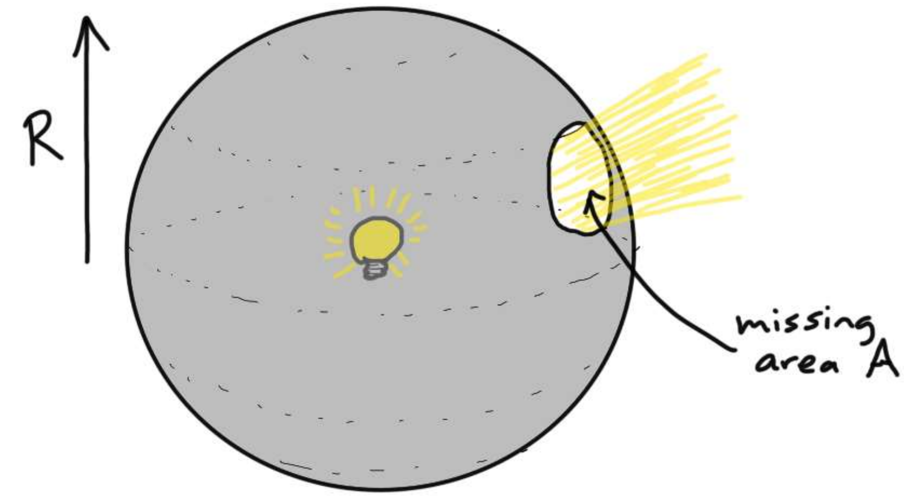


A) 100W
B) 100W × A
C) 100W × A/R^2
D) 100W × $A/(\pi R^2)$
E) 100W × $A/(4 \pi R^2)$

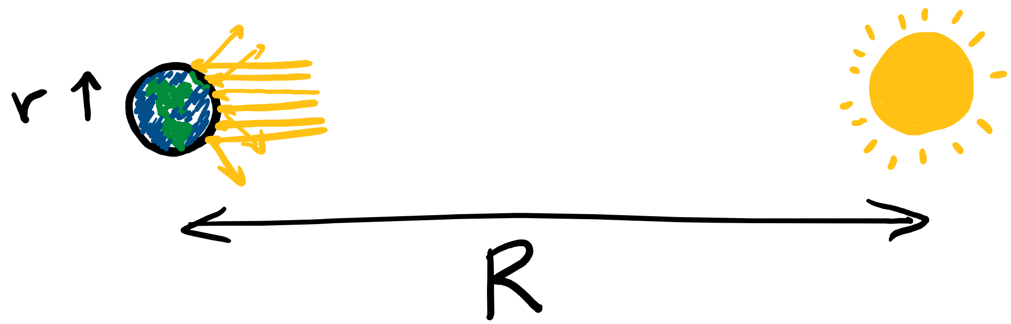
- Light spreads out uniformly
- Power leaving bulb = power reaching sphere
- Hole covers fraction $\frac{A}{4\pi R^2}$ of sphere
- So power of light coming out is $\frac{A}{4\pi R^2} \times 100W$

The power from the sun is: $H_{Sun} = A_{Sun} \cdot \sigma \cdot T_{Sun}^4$

$A_{Sun} = 4\pi R_{Sun}^2$ (have $e \approx 1$)

What is the power $\mathbf{H_{In}}$ of solar radiation absorbed by the Earth? Answer in terms of H_{Sun}, the albedo **a** (fraction of sunlight reflected) and the parameters r and R shown below.

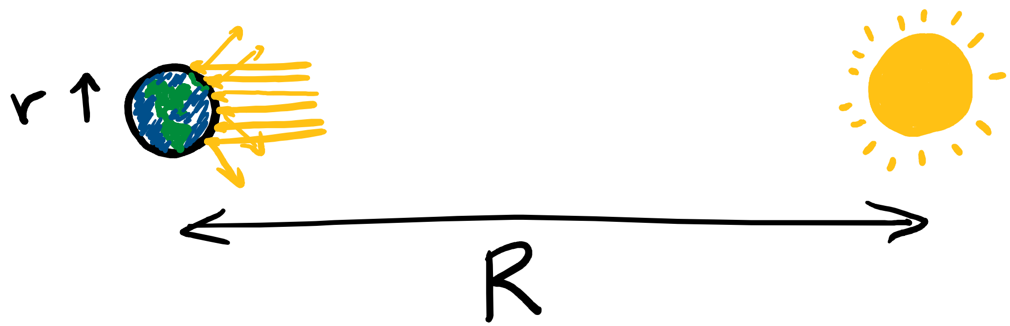
Hint: think about the first clicker question.



Click A when you are done (and do the extra part below).
Click B if you are stuck.

EXTRA: If $H_{Sun} = 3.86 \times 10^{26}$W and $R = 1.5 \times 10^{11}$m, how much solar energy per second goes through an area of $1m^2$ at the distance R?

What is the power **H_{In}** of solar radiation absorbed by the Earth? Answer in terms of H_{Sun}, the albedo **a** (fraction of sunlight reflected) and the parameters r and R shown below.



A) $H_{Sun} \cdot \frac{\pi r^2}{4\pi R^2} \cdot a$

B) $H_{Sun} \cdot \frac{\pi r^2}{4\pi R^2} \cdot (1 - a)$

C) $H_{Sun} \cdot \frac{2\pi r^2}{4\pi R^2} \cdot a$

D) $H_{Sun} \cdot \frac{2\pi r^2}{4\pi R^2} \cdot (1 - a)$

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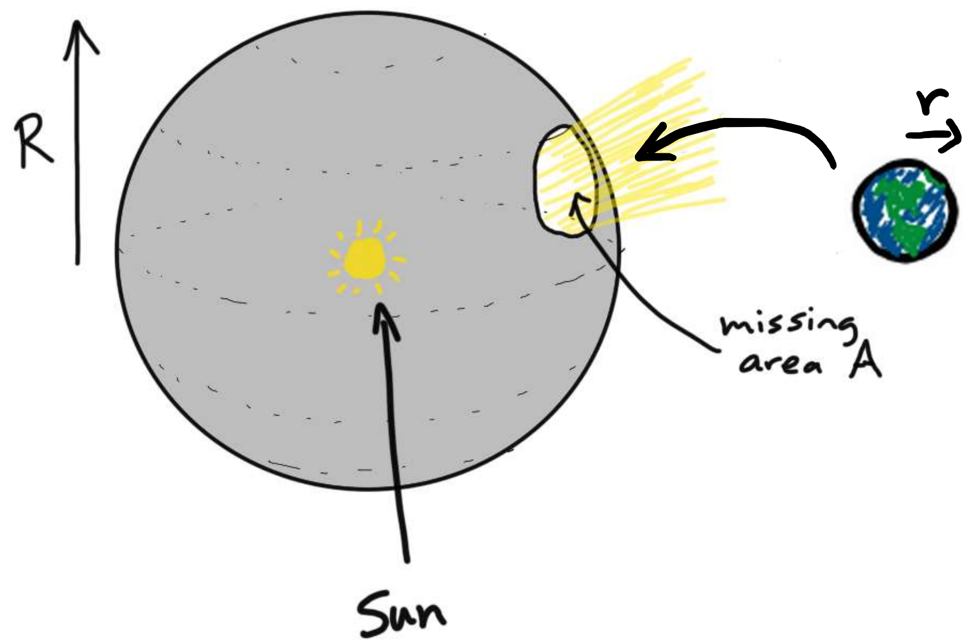


Power through hole is

$$H_{Sun} \cdot \frac{A}{4\pi R^2}$$

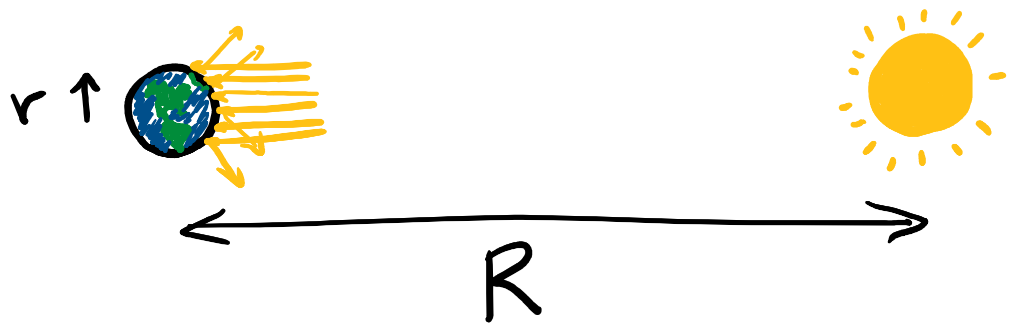
If $A = \pi r^2$, Earth will just fit.

Power hitting Earth is

$$H_{Sun} \cdot \frac{\pi r^2}{4\pi R^2}$$

Fraction $(1-a)$ is absorbed, so $H_{In} = H_{Sun} \frac{\pi r^2}{4\pi R^2}(1-a)$

What is the power H_{In} of solar radiation absorbed by the Earth? Answer in terms of H_{Sun}, the albedo **a** (fraction of sunlight reflected) and the parameters r and R shown below.



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E) $H_{Sun} \cdot \frac{4\pi r^2}{4\pi R^2} \cdot a$

The solar constant.

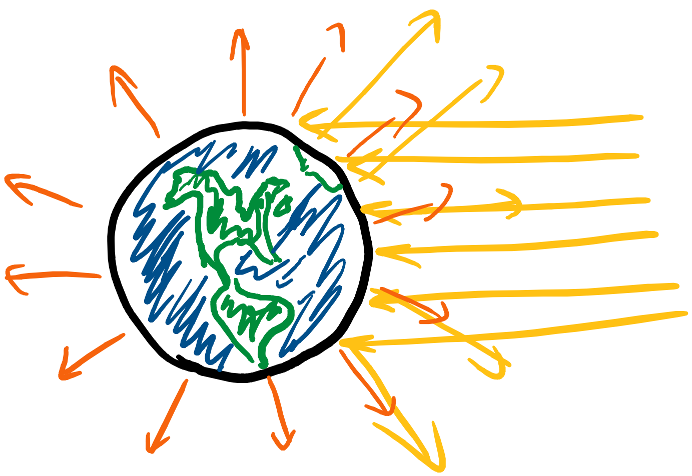
- At Earth's orbit, the power per unit area (or INTENSITY) of sunlight is

$$I_{sc} = \frac{H_s}{4\pi R^2} = 1367\ W/m^2$$

"solar constant"

The heat current into the earth due to sunlight is $H_{in} = \pi r^2 (1-a) I_{sc}$

Calculate the equilibrium surface temperature T in terms of **a**, **I$_{SC}$**, **r**, **σ**, and the emissivity **e**.



H_{in} : absorbed sunlight

H_{out} : IR radiation

recall: $H_{rad} = Ae\sigma T^4$

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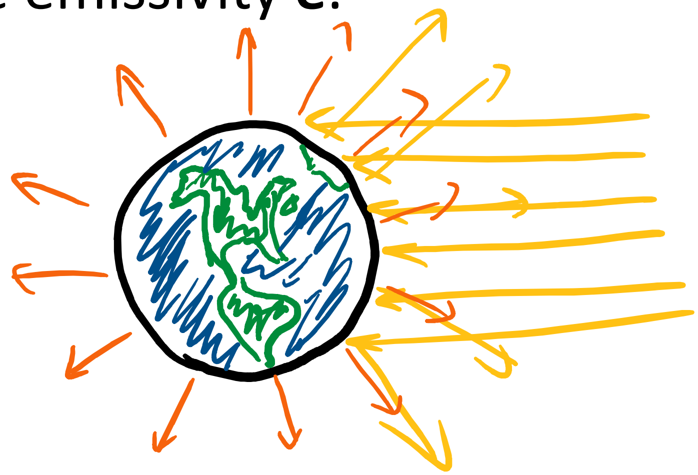

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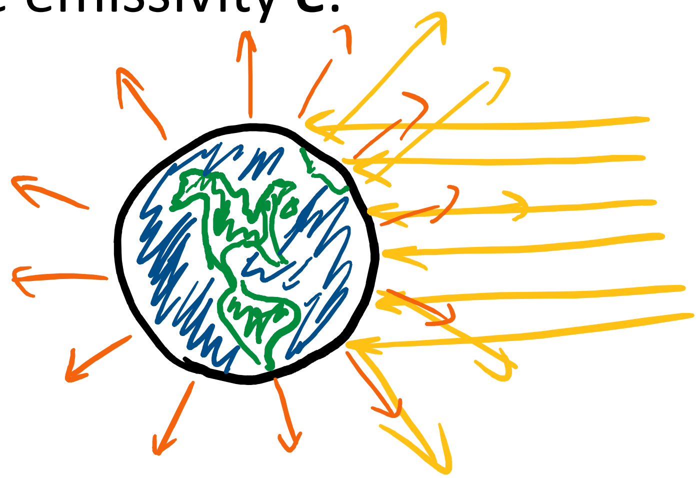


H_{in} : absorbed sunlight

H_{out} : IR radiation

We have $H_{in} = H_{out}$ (steady state)

$$\pi r^2 (1-a) I_{sc} = 4\pi r^2 \cdot e \cdot \sigma \cdot T^4$$

$$\star \quad T = \left[\frac{(1-a) I_{sc}}{4 e \sigma}\right]^{\frac{1}{4}} \quad \star$$

$$\star \quad T = \left[\frac{(1-a)I_{sc}}{4e\sigma}\right]^{\frac{1}{4}} \quad \star$$

The numbers: surface of the Earth has $e \approx 1$ for IR radiation.

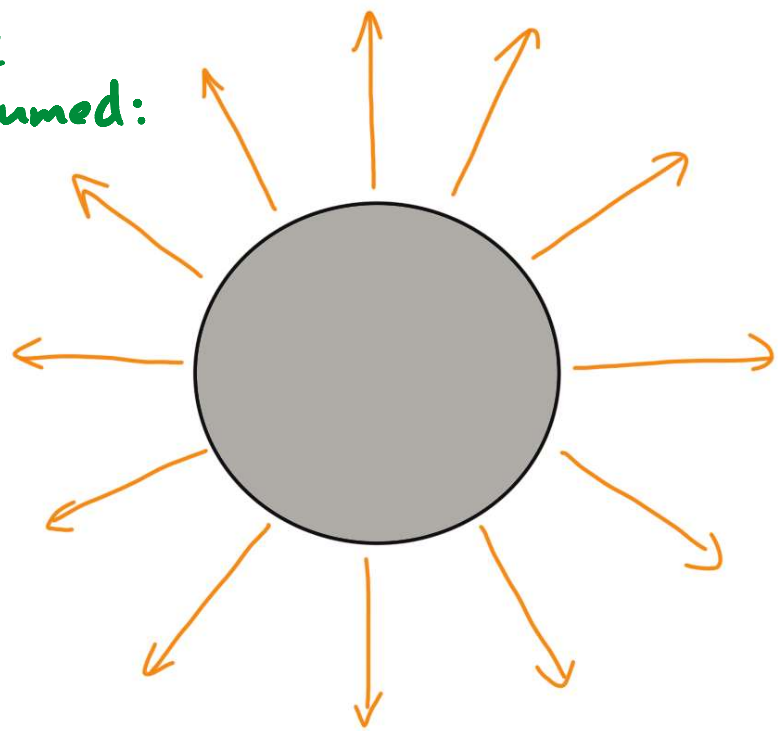
$I_e = 1367\, W/m^2$ $\qquad a = 0.37$ $\qquad \sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

These give $T = -15°C$

Something is off...

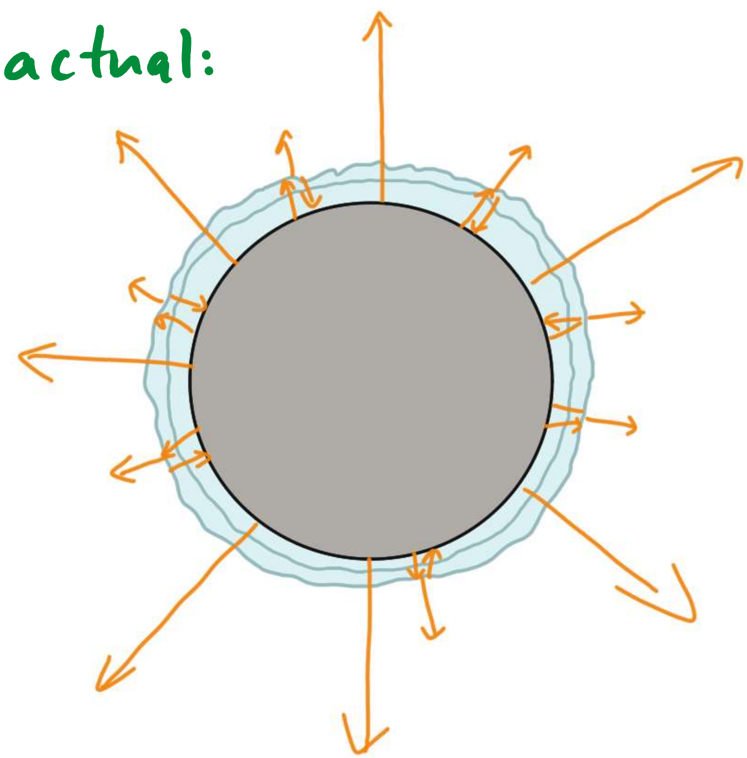
Actual surface temperature is larger due to the **GREENHOUSE EFFECT**: some IR radiation is absorbed by "greenhouse gases" + re-emitted back to Earth.

we assumed:



$e = 1$

actual:



$e \approx 0.6$

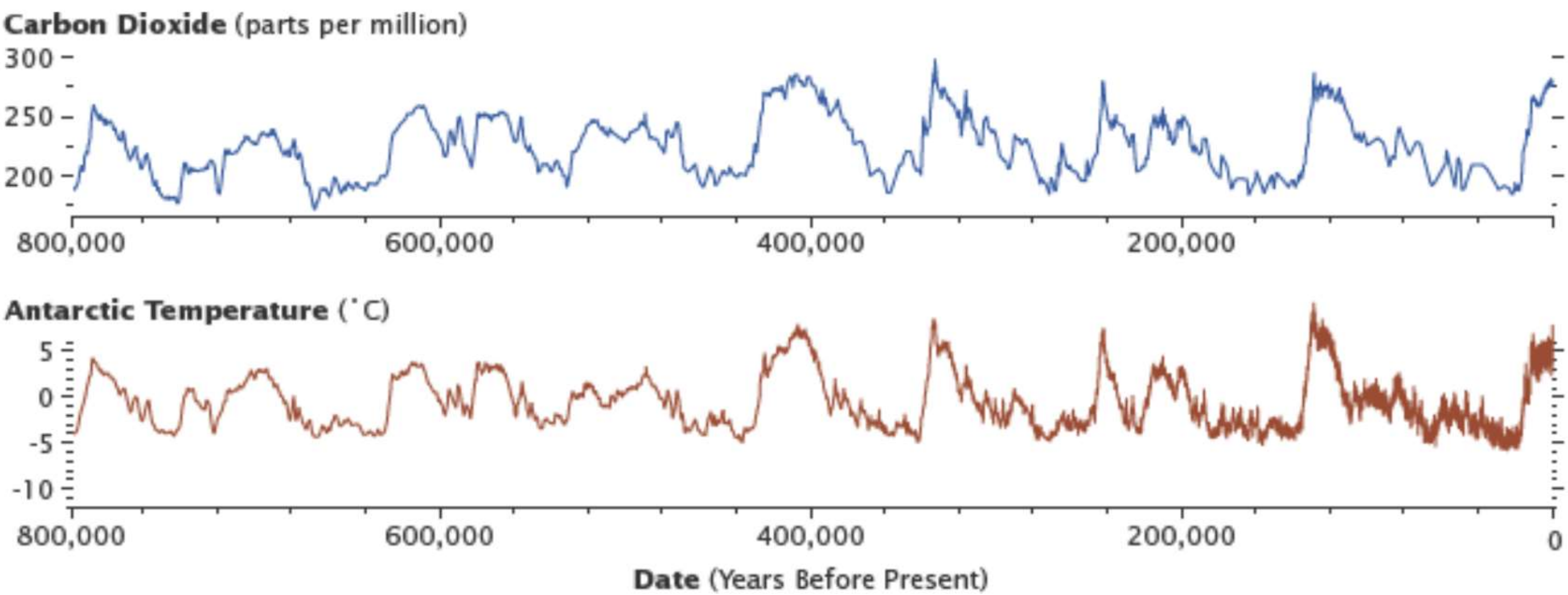
★ $T = \left[\frac{(1-a)I_{sc}}{4e\sigma}\right]^{\frac{1}{4}}$ ★

Lower e ⟹ higher T

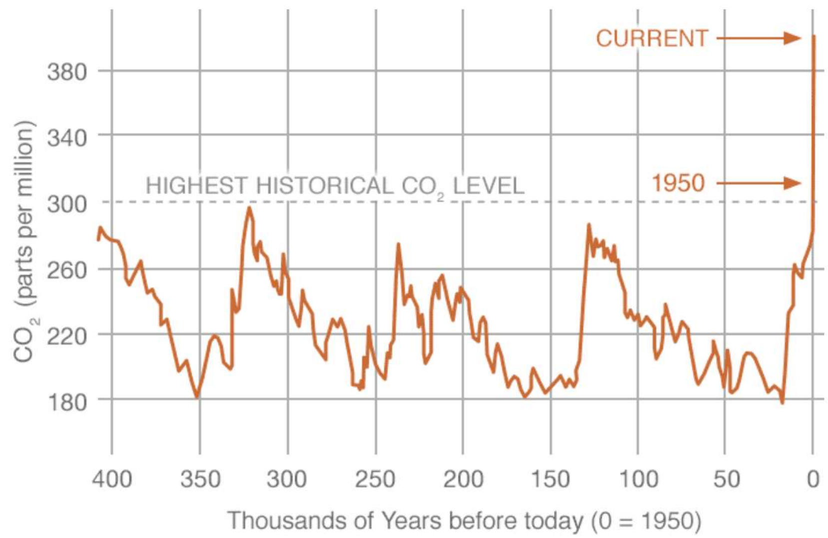
Real $e \approx 0.6$ gives $T = 14.5°C$

But e can decrease e.g. due to increasing CO_2 concentration in atmosphere. ⟶ Global warming

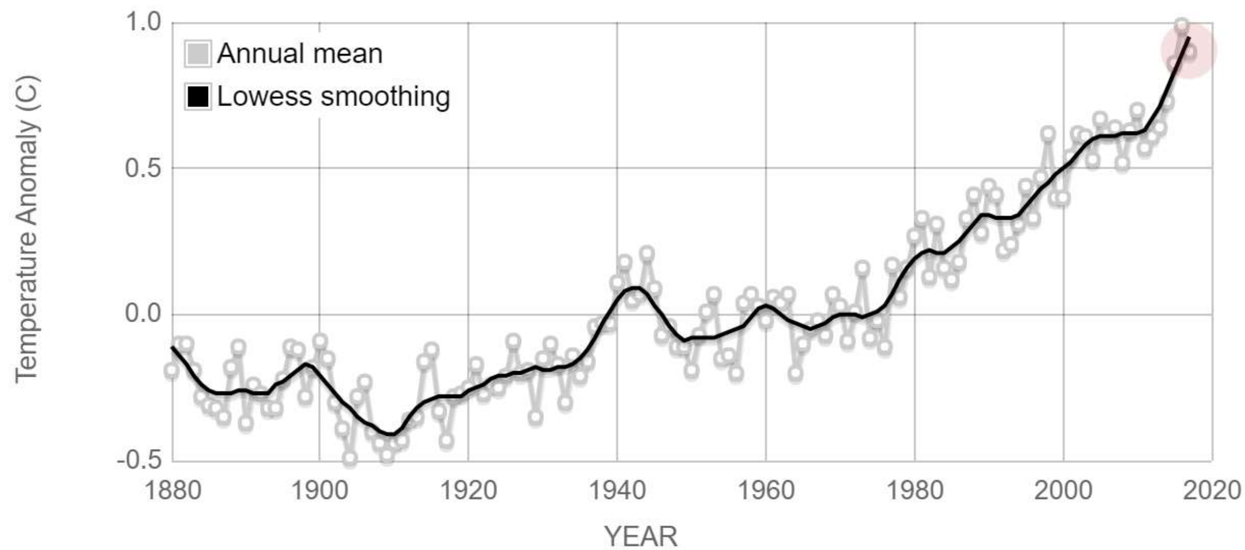
CO_2 correlates closely with temperature



CO_2 levels:



Temperature:



Almost all climate scientists believe this rise due to human activity